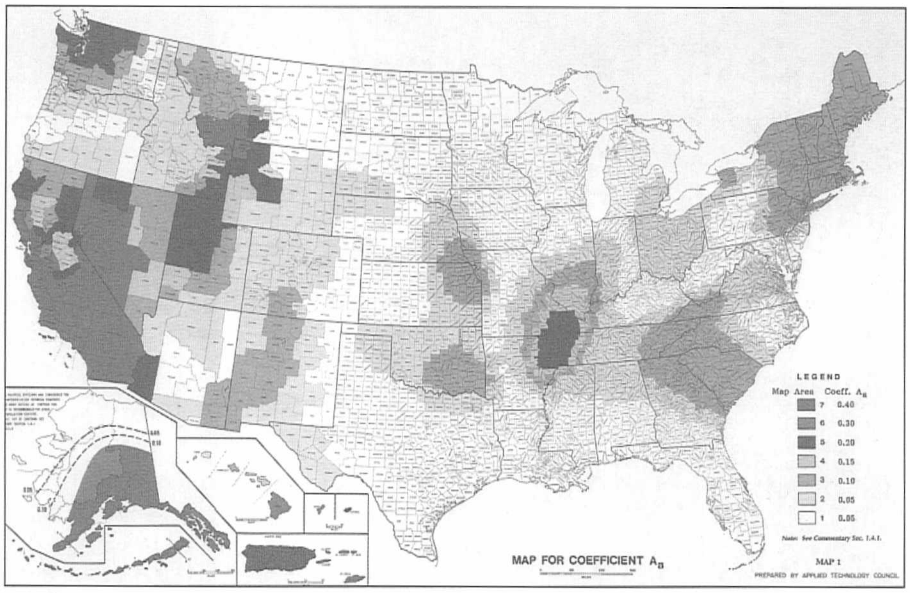

FIGURE 3.5 U.S. seismic hazard map based on effective peak acceleration.

This seismic hazard map, published by the Applied Technology Council in 1978, shows 7 zones of effective peak acceleration with a 10 percent probability of occurring in a 50-year period. Each county is assigned a value. This map became the basis for the first NEHRP Provisions in 1985. (Source: Applied Technology Council, 1978)

Provisions.[10] ICBO has long been a leader in seismic code development; BOCA incorporated the 1988 *NEHRP Provisions* into the 1992 BOCA *Supplement*; and SBCCI incorporated the 1988 *NEHRP Provisions* in the 1992 amendments to the SBC. Thus, all communities **that adopt the most recent editions of these codes** have the most advanced seismic codes available.

The Federal Government Requires Seismic Design for All Its Buildings

Signed in January 1990, presidential Executive Order 12699 required all federal agencies by February 1993 to issue regulations or procedures that incorporate cost-effective seismic safety measures for all *new* federal buildings and buildings that are leased, assisted, or regulated by the federal government. All of the affected federal agencies have adapted one or more minimum standards for seismic safety and have issued the required regulations or procedures.

Because of EO 12699, it is in the best interests of local governments to adopt seismic codes. To best facilitate the possibility of federal financial assistance for new buildings, local governments would be well advised to adopt one of the model codes that have been found to be seismically adequate. For example, the federal agencies providing financial assistance for housing construction (VA, FHA, HUD) all now require adequate seismic design and construction.

In conjunction with EO 12699, Executive Order 12941 (December 1, 1994) directs federal agencies to evaluate *existing* federally owned and leased buildings to identify buildings that are potentially hazardous and to plan for the seismic rehabilitation of those so identified.[11]

Both executive orders are significant in that the federal example encourages state and local governments to make seismic design more prevalent throughout the nation. They also increase the number of experienced seismic designers and contractors.

Seismic Codes Account for Variations in Earthquake Hazard across the U.S.

All the model codes include a seismic hazard map that indicates likely levels of earthquake groundshaking in every part of the United States. The latest adopted maps depict the peak ground acceleration that has a 10 percent probability of being exceeded every fifty years. New maps based on spectral accelerations have recently been issued by the U.S. Geological Survey and are currently under consideration for use in future code editions (see Appendix A).

The code requirements reflect the fact that some places are more prone to earthquakes than others. Sometimes local officials question whether their jurisdiction warrants seismic design. Because of the seismic hazard map in the code, this decision need not be made by individual local officials—the codes themselves require the appropriate level of seismic design (which in some cases is *no* seismic design) for every county in the United States. The zone boundaries are based on probability: a structure on one side of a zone line is not markedly safer than a structure immediately on the other side. But these maps do represent a consensus of informed scientific opinion on the likelihood of earthquake ground-shaking and its effects. By using these maps as guides to design, we reduce the overall chances of damage to buildings in a region.

Seismic Codes Are Designed to Help Buildings Resist Earthquake Shaking

It is important to understand that seismic codes result in earthquake-*resistant* buildings rather than earthquake-*proof* buildings. Their purpose is to protect life safety by preventing building collapse and allowing for safe evacuation. The contents and interiors of buildings, even those of well-designed buildings, may receive extensive damage, and critical functions of a building may cease. And structural damage may occur from major earthquake ground-shaking. According to the Structural Engineers Association of California, structures built according to a seismic code should:

- resist minor earthquakes undamaged,
- resist moderate earthquakes without significant structural damage even though incurring nonstructural damage, and
- resist severe earthquakes without collapse.[12]

Occasionally even a code-designed building may collapse due to unique site conditions or other factors. A report completed by the Earthquake Engineering Research Institute (EERI) just prior to the Northridge, California, earthquake summarized expected earthquake damage to buildings designed according to the 1991 UBC. It stated, for example, that shaking of Intensity VIII could cause moderate damage (easily repairable) to 10 to 30 percent of code-designed buildings, and extensive damage (long-term closure, difficult to repair) to 0 to 5 percent of code-designed buildings.[13] This was the intensity level experienced by much of the San Fernando Valley in January 1994, and buildings performed generally as expected.

Seismic Codes Reflect Social Judgments Regarding Acceptable Risk and Cost

Seismic design standards reflect society's balancing of the risks versus the costs of designing to withstand that risk. They do this in two ways: by designing for (a) an appropriate-sized event and (b) an appropriate performance goal. Society cannot justify the expense of designing for large but highly improbable events. So we select a ground motion event—called the *design event*—that although large and rare has a reasonable chance (10 percent) of being exceeded during a building's lifetime (50 years). The probability selected reflects society's attitude toward risk.[14] This is similar to the philosophy long used for flood protection: Society is willing to absorb the cost of designing for a 100-year flood, but with the exception of critical facilities it would not make economic sense to design for the 500-year or 1,000-year flood.

The goal of seismic codes is to ensure that buildings will not collapse, thereby killing those inside, if shaken by the design event. Seismic codes are for "life safety" and are not aimed at completely preventing damage to existing buildings (see Fig. 3.4). Additionally, it is important to realize that there is a 10 percent chance of an earthquake occurring that exceeds the design event.

Seismic Codes Are Inexpensive

Seismic codes add relatively little to the costs of a structure. To assess the costs of the *NEHRP Provisions* (seismic provisions), the BSSC in 1985 contracted seventeen design firms from nine U.S. cities to per-

Increase in Cost by Building Type Resulting from Seismic Design

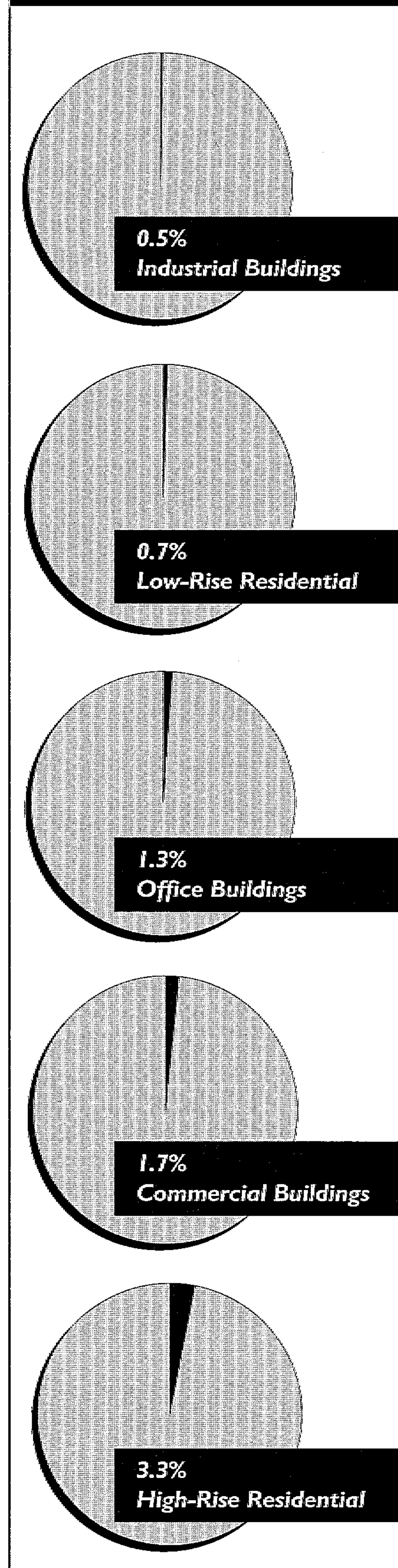

FIGURE 3.6 *The extensive damage in Armenia in 1988 can be attributed to the lack of seismic-resistant design and construction. The same limitations are true of existing building stock throughout the United States. (Photo: NOAA)*

Damage costs from earthquakes are estimated to be reduced substantially by seismic codes. For a magnitude 8 earthquake affecting Memphis, damage estimates are $10.4 billion without codes and $5.81 billion with codes—a savings of about 50 percent. For a magnitude 6 earthquake, damage estimates are $1.49 billion and $.49 billion, respectively—an even larger savings of about 66 percent.

form two designs for each of several typical building types, first using the existing local code and then using the seismic provisions. They found the average increase in total costs to be 0.7 percent for low-rise residential buildings, 3.3 percent for high-rise residential buildings, 1.3 percent for office buildings, 0.5 percent for industrial buildings, and 1.7 percent for commercial buildings. Cities with previous seismic design provisions in their codes averaged much smaller cost increases (0.9 percent) than did cities with no seismic codes at all.[15]

A 1992 study by the National Association of Home Builders (NAHB) for the Insurance Research Council examined the incremental costs of building single-family residences to 1991 *NEHRP Provisions*. They found that "builders can construct houses providing for life safety in earthquakes at a very reasonable added cost—less than 1 percent of the purchase price of a new home in most instances."[16]

Costs of seismic design can vary. It is easier to provide seismic design for simple-shaped structures, with basic geometric shapes such as a square, and cheaper to do if seismic considerations are integrated into the earliest stages of building design. In certain situations, the costs for the structure are relatively small in proportion to the total project costs. This occurs if the project has expensive contents or high land values. If this is the case, the cost of seismic-resistant design becomes a smaller proportion of the total project cost.

Studies Indicate That the Benefits Outweigh the Costs

A few studies have attempted to look at the costs and benefits of seismic design provisions. The studies generally indicate that the costs of seismic-resistant construction are justified. Such studies, however, cannot easily provide definitive answers. Although the direct costs of codes are relatively easy to estimate, the benefits of codes (future damages and injuries that will not occur) are more problematic. These studies are limited by the number of assumptions that must go into such models and by the difficulty of quantifying life loss, injury, and indirect effects on the economy resulting from an earthquake. Nevertheless, benefit/cost models can provide useful guidance to decision-makers and are being used with increased frequency.

In a 1987 study led by William Schulze of the University of Colorado, the costs of seismic codes in southern California were compared to the benefits of protection from an earthquake on the San Andreas fault. They found costs and benefits roughly equal within the accuracy limits of their model. However, this model was very limited in that it ignored all other southern California earthquake sources and did not consider benefits of reduced emergency services, injuries, and uninterrupted economic activity.[17] A more comprehensive model that would account for these factors would likely find seismic codes in southern California to be worth the cost.

A 1992 study, *Physical Damage and Human Loss: The Economic Impact of Earthquake Mitigation Measures*, funded by the National Committee on Property Insurance (now IBHS), analyzed the estimated costs and benefits of seismic building codes for Memphis, Tennessee, assuming damage from magnitude 6 and 8 earthquakes in the southern New Madrid fault zone. It found that benefits exceed costs by a factor of 1.8 for the magnitude 6 event and 10.3 for the magnitude 8 event. Moreover, the benefit-cost ratio averaged over a forty-year time horizon, accounting for the expected probability of earthquakes in that time period, was estimated at 3.3. Thus, the expected damage over forty years is more than three times greater than the costs of building to code. Furthermore, the benefits are underestimated because they do not account for the benefits of reducing fatalities, injuries, fire potential, or economic losses. This recent study provides valuable analytic support to the claim that seismic building codes are cost-effective, even in the central United States.[18]

NOTES

1 Bruce A. Bolt, *Earthquakes*, W.H. Freeman and Company (NY), 1993.

2 E.g., Fratessa, Paul F., "Buildings" (chap. 3), in *Practical Lessons from the Loma Prieta Earthquake*, National Academy Press, 1994.

3 Earthquake Engineering Research Institute, "Northridge Earthquake of January 17, 1994," *Earthquake Spectra*, Supplement to Vol. 11, April 1995.

4 Cited in Chung, Riley, ed., *The January 17, 1995 Hyogoken-Nanbu (Kobe) Earthquake: Performance of Structures, Lifelines and Fire Protection Systems*, National Institute of Standards and Technology, NIST Special Publication 901, July 1996.

5 Cited in Shinozuka, Masanobu, "Summary of the Earthquake," in *NCEER Response: Preliminary Reports from the Hyogo-ken Nanbu Earthquake of January 17, 1995*, National Center for Earthquake Engineering Research, State University of New York at Buffalo, January 1995.

6 Wyllie, Loring A., Jr., and John R. Filson, eds., *Armenia Earthquake Reconnaissance Report, Special Supplement to Earthquake Spectra*, Earthquake Engineering Research Institute (Oakland, CA), August 1989.

7 "The March 25, 1993, Scotts Mills Earthquake—Western Oregon's Wake-Up Call," *EERI Newsletter*, Vol. 27, No. 5, May 1993.

8 Esteva, Luis, "Seismic Zoning, Design Spectra and Building Codes in Mexico," in *Proceedings of the Fourth International Conference on Seismic Zonation*, Vol. 1, Earthquake Engineering Research Institute, August 1991.

9 This history of seismic codes comes from a number of sources, most notably: Beavers, James E., "Perspectives on Seismic Risk Maps and the Building Code Process," in *A Review of Earthquake Research Applications in the National Earthquake Hazards Reduction Program: 1977–1987*, Walter Hays, ed., U.S. Geological Survey Open-File Report 88-13-A, 1988, 407-432; Whitman, R.V., and Algermissen, S.T., "Seismic Zonation in Eastern United States," *Proceedings, Fourth International Conference on Seismic Zonation*, Vol. I, Earthquake Engineering Research Institute, 1991, 845-869; Martin, H.W., "Recent Changes to Seismic Codes and Standards: Are They Coordinated or Random Events?" *Proceedings, 1993 National Earthquake Conference*, Vol. II, Central U.S. Earthquake Consortium, 1993, 367-376.

10 As part of implementing EO 12699, the Federal Government reviewed all three model codes to see if they were consistent with the 1988 *NEHRP Provisions*. In 1992 they declared that the following codes meet those provisions: 1991 UBC, 1992 BOCA supplement, and the 1992 SBC amendments. See *Guidelines and Procedures for Implementation of the Executive Order on Seismic Safety of New Building Construction*, ICSSC RP2.1A, NISTIR 4852, June 1992. In a May 17, 1995, Recommendation, the Interagency Committee on Seismic Safety and Construction updated this finding. They found that the 1994 UBC, 1993 BNBC, and 1994 SBC provide a level of seismic safety substantially equivalent to that of the 1991 *NEHRP Provisions*.

11 EO 12941, by adopting the *Standards of Seismic Safety for Existing Federally Owned or Leased Buildings*, by the Interagency Committee on Seismic Safety and Construction (ICSSC), promulgates a set of seismic standards for federally owned or leased buildings. It also establishes five triggers for evaluation and possible mitigation of risks in a building. For example, when there is a change of building function, a building must be evaluated according to the ICSSC standards. See Todd, Diana, ed., *Standards of Seismic Safety for Existing Federally Owned or Leased Buildings, National Institute of Standards and Technology Report NISTIR 5382*, Interagency Committee of Seismic Safety and Construction Recommended Practice 4 (ICSSC RP 4), February 1994.

12 From the 1990 SEAOC Blue Book, cited in EERI Ad Hoc Committee on Seismic Performance, *Expected Seismic Performance of Buildings*, Earthquake Engineering Research Institute, February 1994.

13 EERI Ad Hoc Committee; see note 9.

14 The 10-percent-in-50-year standard is actually an artifact from the initial development of the ATC 3-06 maps. The profession has been moving toward a 2-percent-in-50-year standard as being more reflective of public attitudes toward life safety, and this will be reflected in the 1997 *NEHRP Provisions* (Christopher Rojahn, Executive Director of ATC, March 1997).

15 Building Seismic Safety Council, *Societal Implications: Selected Readings*, FEMA #84, June 1985.

16 National Association of Home Builders, *Estimated Cost of Compliance with 1991 Building Code Requirements*, Insurance Research Council, August 1992.

17 Schulze, William D., et al., "Benefits and Costs of Earthquake Resistant Buildings," *Southern Economic Journal*, Vol. 53, April 1987.

18 Litan, Robert, et al., *Physical Damage and Human Loss: The Economic Impact of Earthquake Mitigation Measures*, The National Committee on Property Insurance (now IBHS), February 1992.